MEDIUM BATCH DIE CASTING

Paper presented to the Institution, Leicester Section, by H. A. Stock.

This paper deals with die casting from the design and production viewpoints. The general sequence of operations is described. Shrinkage allowance, venting, elimination of porosity, and the use of inserts are among the factors considered. The discussion includes references to the maximum casting weight and number of shots per hour, the materials used for die cores and castings, the effect of shrinkage stresses between casting and die, the dimensional accuracy of castings, ejection of castings from the die, and the problem of small quantity die casting.

IN present-day practice, pressure die castings are produced in various ways. One method involves the injection of molten metal under pressure into the dies by mechanical means. An alternative is to pour the molten metal into a cylinder adjacent to or forming part of the dies and exert very heavy pressure by means of a plunger on the solidifying metal thus, in a sense, forcing it into the die cavity by extrusion. Machines of the latter type are almost exclusively used for casting the higher melting-point alloys, and are expensive to operate, owing largely to the very high pressures required. There is a third method of production which is widely used, in which compressed air is applied to the surface of the metal contained in the gooseneck or a reservoir, thus forcing the metal out of the nozzle and into the dies. This method is generally used when casting aluminium alloys.

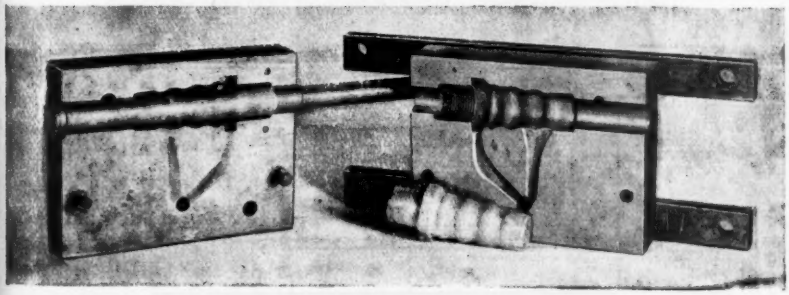

Fig. 1.—A simple die for a hose connection.

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Fig. 2.—A view of a typical die showing the ejector pins

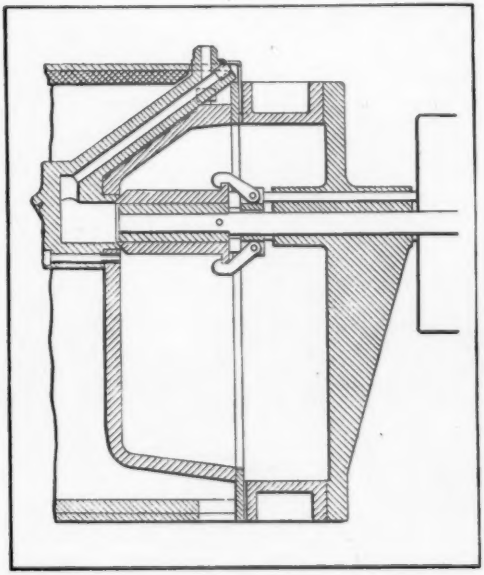

Fig. 3.—A sectional view of a patented injection pump.

A die for producing hose connections is shown in Fig. 1, which also shows one of the castings. The cavity is formed equally in each die half provision being made for holding the long core which forms the central hole in the casting. Since, in this case, few castings were required, this core was knocked out with a soft hammer. The sprue hole can be clearly seen, and the runner proceeding from it up to the gate at the edge of the cavity controls the velocity of the metal passing into the cavity. This is very important, because if the cavity is filled too quickly, some air may be trapped and a porous casting may result through encirclement. To overcome this danger, it is some times necessary to provide air vents, either in the form of

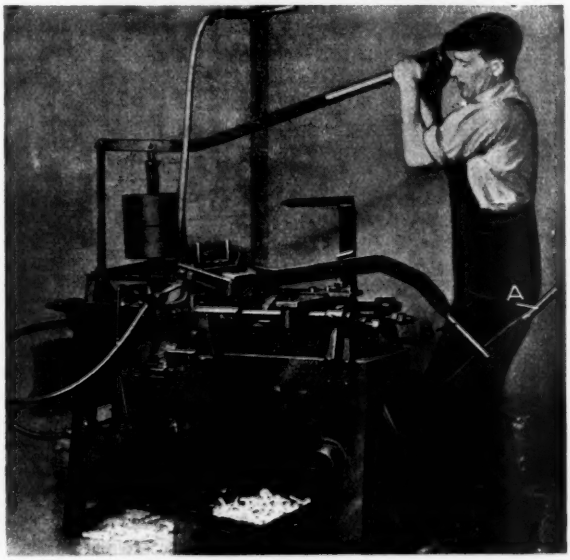

Fig. 4.—A view of the machine on which the pump shown in Fig. 3 is employed.

grooves in the die plate or flats or grooves on the sides of the core and ejector pins.

In the die illustrated in Fig. 2, not only the sprue hole and runner but also the ejector pins which have pushed the casting out of the cavity may be seen. Around the cavity there are four small pins called return or surface pins. As the two die halves are brought

together again, these four pins return the ejector pins to the casting position in readiness for the next shot. This die gives an output of 180 castings per hour.

A patented pump arrangement for applying pressure to molten metal is shown in Fig. 3. The outer casing is the furnace body, in which is supported the metal reservoir carrying the sump gooseneck. A chamfered seating is provided at the top of the well formed by the gooseneck within the reservoir which matches with a sleeve. The latter can be lifted from the gooseneck seating, in order to allow a fresh charge of metal to flow in. The sleeve contains a plunger which can slide within it.

Fig. 5.—A die casting in zinc base alloy with an external thread.

The pump just desribed forms part of the machine shown in Fig. 4, and occupies the rear end, where it is slung on two trunnions. These trunnions slide on the guide bars, and two screws at the front end provide height adjustment to enable the gooseneck nozzle to be aligned with the sprue hole in the rear die slide. In the illustration, the operator has just cast the shot and is still pulling down the pump lever, the dies having been locked previously by the lower lever *A*. He will next raise the pump lever, thus lifting the plunger, already shown, within its sleeve. Continued lift raises the sleeve

to allow a fresh charge to enter the gooseneck ready for the next shot. As the lever is lowered, the sleeve falls back on to its seating. The operator then releases the die locking lever *A*, and raises the remaining lever *B*, which is not part of the machine but of the dies. Movement of the lever *B* withdraws the vertical core pins

Fig. 6.—A die cast ignition control housing.

within the dies, and continued movement of the die-locking lever ejects the castings, which fall down a chute in the bed of the machine and into the box underneath.

The casting shown in Fig. 5 is produced in a two-cavity die, and an output of 300 per hour is obtained. The external thread at the upper end is cast. The thread, together with all other dimensions, is accurate for size and shape within 0.002 in.

In Fig. 6 is shown an ignition-control housing which is cast at the rate of 230 per hour. The weight of the part is about $4\frac{1}{2}$ oz., and apart from trimming it requires no machining after it leaves the die. Fig. 7 shows a die cast gear for an air speed instrument.

A die-cast twist-drill stand is shown in Fig. 8. Several hundred thousands of these castings have been produced from the original dies which are still working satisfactorily, and the only maintenance cost in connection therewith has been the occasional replacement of some of the small core pins.

It is, of course, sometimes necessary to tap holes in die castings, not always because the threads cannot be cast, but because the extraction of threaded cores slows up casting production too much.

Modern tapping machines are of assistance in this connection. That shown in Fig. 9 will tap holes in die castings up to $^{5}/_{16}$ in. diameter B.S.F. thread to a depth of $\frac{3}{8}$ in. at the rate of 500 holes per hour, the table being slotted to take any necessary locating jigs. The spindle of this machine is friction-driven, and power may be taken from an independent motor or direct from the main line shaft.

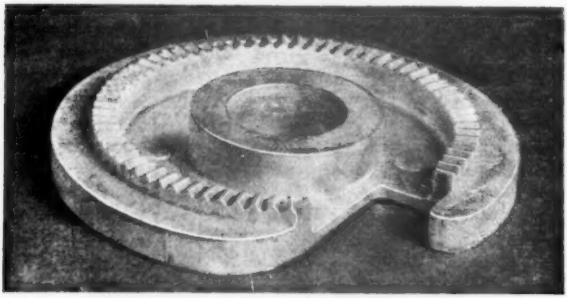

Fig. 7.—A die cast gear for an air speed instrument.

Shrinkage Allowance.

In making the dies, the designer or die sinker must take into consideration the shrinkage of the metal when cooling, and this would at first sight appear quite simple, because the free contraction of several of the well known zinc-base alloys is 0.006 in. per linear inch. The actual contraction, however, varies appreciably with the job to be produced. Assume, for example, that there are two rings

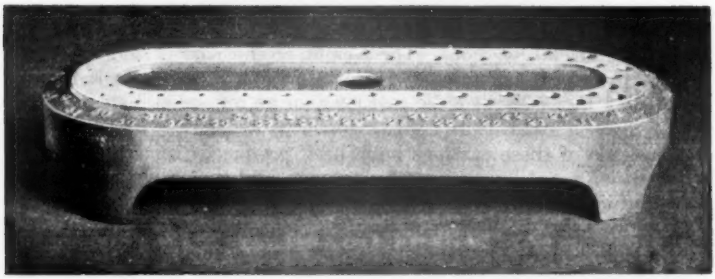

Fig. 8.—A die cast twist drill stand.

of, say, 3 in. diameter, one having a central hole $2\frac{3}{4}$ in. in diameter and the other a hole $\frac{1}{2}$ in. in diameter. The thin section of the first ring when cooling on the core, will permit of considerable stretch, and measurements of the ring afterwards may show that the reduction in diameter by cooling is as low as 0.002 in. per linear inch. The other casting, owing to its heavy section, will grip the core very strongly, and when it has been removed will spring in. Subsequent measurement will show that the reduction in diameter on

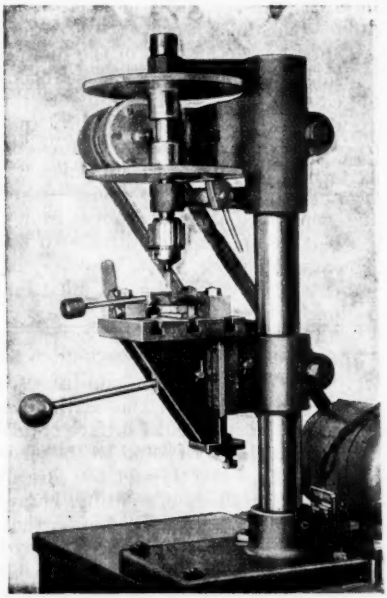

Fig. 9.—A tapping machine suitable for threading holes in die castings.

cooling in this case is very nearly 0.006 in. per linear inch. If a disc of 3 in. diameter was cast having no hole in it at all there would be nothing to restrict the shrinkage, and consequently, it would shrink at the rate of 0.006 in. per linear inch. This is, of course, a very elementary example of one of the things which has to be allowed for.

Venting.

It is now proposed to deal with a few of the thorny problems which will confront newcomers to the production of die castings

by the pressure process. In the first place, wherever possible, the parts required should be designed for die casting. The best results cannot be secured by deciding suddenly that a part which has hitherto been made as a sand casting should be put in hand for production, exactly in its existing form, as a die casting. It must be remembered that when a casting is made in sand, it is poured comparatively slowly, thus enabling the air already in the mould to escape freely up the riser and feeder openings. Further, the sand mould, being of a porous nature, allows a certain amount of air and gases produced by the turbulent metal to escape through the sand. When using steel dies, however, the conditions are very different, as the joints, or parting line of the die faces, provide the only escape for air and gases unless special arrangements are made.

In pressure die casting, effects very similar to those obtained in ordinary foundry work are likely to be met with, and it is more than ever essential to get rid of air trapped in the cavity, and of gases which may be formed as a result of the turbulence of the incoming metal. It is occasionally possible to assist considerably in this direction by filing some very shallow grooves from the edge of the cavity across the parting-line face of the die to the outside edge. Such grooves or escape channels must, however, be of very small sectional area, otherwise they will become filled immediately with metal, and their object will be defeated.

Provision for venting can also be made on the ejector pins. It will be recalled that ejector pins are generally used to push the castings out of the front half of the die, and usually operate within the cavity, leaving slight marks on the castings produced. If a slight flat is provided on the cylindrical surface of one or more of the pins extending right from the cavity and to the ejector plate which carries the pins, the air will escape through the tiny aperture formed.

This is one of the best methods of venting, because the pins are moved to eject the castings after every shot so that the vent provided is automatically kept clear. It is easy to prove whether the vent openings are functioning by smearing the inside of the cavity lightly with oil before casting. When the shot is made the hot metal then causes the oil to smoke, and the smoke is forced through any vents provided. Fixed core pins, such as are employed to form holes and cavities in the casting, can be similarly provided with minute flats on their sides, but such vents are, of course, more likely to become choked with metal.

The Elimination of Porosity.

One of the most important things which the designer and die caster has to bear in mind is the question of porosity of castings, caused during cooling, particularly with castings containing heavy sections. If an attempt was made to cast a 2 in. cube of metal

it would almost certainly be seriously porous if it were shot at the normal speed. Whatever precautions were taken it would be slightly porous, but if the pump were operated with discretion the casting should be fairly solid, and in such cases there is another way of promoting solidity.

In sand casting a riser is provided, which together with the runner, acts as a feeder. As the casting cools, some of the still molten metal in the riser and runner is drawn downwards and prevents the formation of blow holes and sunk surface spots. In a pressure die casting the runner cannot be used as a feeder because the gate must be thin, but a riser can be provided. A hemispherical cavity is formed adjacent to the cavity proper, and joined thereto by a groove of fairly large cross section, so that as the casting shrinks it will draw a certain amount of metal through the groove from the feeder cavity. As it is necessary to ensure that the metal in the feeder remains molten until last, the feeder cavity must be located in the hottest part of the dies. This is not always easy. A 2 in. cube is not an ideal die casting, and the great point to bear in mind when designing for die casting, is that all wall thicknesses should be as uniform as possible, and they should not be joined to heavy sections such as bosses.

The Use of Inserts.

There are numerous die casting wrinkles enabling parts to be produced which positively cannot be made by any other method. Suppose, for instance, that a casting had to be made with one or more holes for lubricating rotating shafts, and that for certain reasons it was impossible to lubricate the bearings internally. An oil hole could in that case be cored in during casting, or drilled afterwards. But suppose, further, that adjacent bearing holes were so spaced that it was impossible to provide a straight hole for the oil and that the hole had to bend around obstructions. It is obvious that such a hole could not be drilled, nor could a bent core be used unless it formed an arc of a circle, in which case it could be extracted circumferentially. If correctly bent tubes are provided, however, the die caster can insert these tubes in the die cavity before the castings are made, locating the tube at each end for casting purposes. When the shot is made the tube is completely enclosed in the die casting and provides a clear hole right through to the bearing.

Although zinc-base alloy bearings wear very well, there are, of course, many other bearing mentals which are better, and so it is sometimes decided to cast in position bushes of phosphor bronze or other material. Similarly, screws, pins, and many other inserts can be cast in position, and if their duties are arduous they can be very strongly keyed if the inserted portion is first flattened, knurled, notched, or even bent. The only point to bear in mind so far as

the dies are concerned is that the portion of the insert which is to project from the finished casting must be of correct shape and size in order to fit accurately the aperture which must be provided for it in the die. Car door and similar handles have their square steel shanks cast in position. Electric motor armatures have the iron laminations cast in position, also pole pieces. Screws with ornamental heads often have a die cast head with a steel screw shank insert.

Die Design.

Turning now to the designing of dies for any particular job, the number of castings required has naturally a decisive effect. The principal items to be considered are die cost and operating cost. To a large extent one is dependent on the other. So far as the dies are concerned, obviously the cavity has to be provided whether 300 or 3,000,000 castings are to be made, but in the case of a small quantity one would, for example, omit the casting of screw threads, either externally or internally, and would cut them afterwards with a die or tap. The coring of some holes might be omitted, owing to the cost of providing core slides and operating mechanisms, and similar economies could be effected in other directions. Provided that the cost of the total quantity of finished castings, including the cost of dies and subsequent machining operations, is less than the cost of similar articles produced by any other method, then one would say that the part is economical to produce by die casting even if as few as 100 are required.

Advantages of Die Casting.

The cost of modern zinc-base alloys is not much greater than that of iron and less than that of brass, and if by die casting a machining operation can be eliminated then it pays to consider this method.

Die castings can be produced uniformly within modern production machining tolerances. Important dimensions should, however, always be emphasised to the die designer. It is but rarely necessary to do any machining on a die casting.

Discussion

MR. J. RUSSELL-GIMSON (Section President) in the chair: We have had a most interesting address from Mr. Stock, and one which I think will probably be new in its essentials to many of us. Certainly a great deal of the information is new to me, and in the one or two points which I am going to put I shall no doubt display sublime ignorance of the subject. One thing I was very surprised to hear was that die castings are turned out at 300 per hour, because I should never have thought that any metal would have solidified at the rate of five a minute, especially when the dies must have become heated as the result of the constant passage of molten metal. I was wondering whether there was any difficulty in getting the castings out of the dies without damage, i.e. if it was necessary to make the dies of any particular material, or whether any particular material should be put into them to prevent sticking. I remember he did mention greasing, but I take it that was for getting the castings out easily.

MR. BROOME: We have had a very good paper on a very interesting subject, and one which is quite strange to most of us. It was possibly the more interesting to me, because in our business we have had very little to do with die-castings. I do not know very much about them, but it is helpful in our work to broaden our knowledge, and even if we cannot make use of die-castings, we shall know much more about the subject after to-night. Mr. Stock has dealt with his subject very lucidly, and we are very grateful to him. I have very great pleasure in proposing a hearty vote of thanks to Mr. Stock for his lecture to-night.

MR. TAYLOR: During Mr. Stock's lecture I found it very refreshing to hear the suggestion, which seems to me reasonable, that really small quantities of die castings can be ordered. It seems to me that in many cases we have complicated machining operations on relatively small batches, where repeat orders may justify making the batch once every year, or six months, and if the cost of the dies is spread out over two or three years, the expenditure would be justified. Mr. Stock referred to castings of a certain size being capable of a uniformity within .002 in. I take it that means a tolerance of .004 in. Then he showed us an illustration of a twist drill stand. I should have assumed that one of the great difficulties in this would have been to avoid straining and shearing the small pins, bearing in mind the relatively great contraction of the metal in cooling. I should like any information he can give me on that subject. Finally, I should like to ask whether the die-casting of

brass is feasible. I have very great pleasure in seconding the vote of thanks. I think Mr. Stock should be thanked particularly as he has to motor back to Peterborough to-night, on roads the friction of which is none too great.

The vote of thanks was carried by acclamation.

MR. STOCK: I should reply first of all to a question asked by Mr. Gimson, wherein he brings forward a really good point, and that is, the obvious friction which is going to occur on cores upon which the casting has already shrunk with truly tremendous force, because a linear shrinkage of .006 in. per linear inch gives a great strain. There *are* certain lubricants provided, but it is not strictly necessary to use them if the cores are made of a special material. This need not be an expensive material, and on the small cores we almost always use silver steel. According to the book of rules, silver steel is not very good for core pins, but according to the practice of years, we find that silver steel is quite satisfactory, and there is no need to pay a great price for fancy materials. If these cores are highly finished, the necessity for a special lubricant is eliminated. There are preparations on the market for lubrication, and the basis of all of them is graphite.

With reference to Mr. Taylor's questions, the tolerance referred to was a *total* tolerance of .002 in. You can say with reasonable certainty that die-casting can be made to commercial tolerances of .001 per linear inch quite easily,and we have often made castings 3 in. or 4 in. in diameter to .002 in. and kept them standard.

Re the shearing of the pins in the twist-drill stand. There is no question of a shear strain on these pins. Actually, it is a tensile strain. One part of the pin is driven into the die and the other projects, and the casting shrinks round it. When breakage occurs, it is right at the shoulder points, where the casting and the die cavity meet, and the reason for this, I am fairly certain, is because of the difference in temperature. You have very hot metal coming on to the comparatively cold core pin. You do, in the course of time, set up a little weakness but, as I have said, we have made a hundred thousand castings, and we have not had to replace more than five of that total.

MR. TAYLOR: I assume that if you have a die exceeding 4 in. long and two small pins, as that die casting as a whole shrinks there will be a shear strain.

MR. STOCK: The casting has to be got off as quickly as possible. The casting solidifies, to all intents and purposes, instantaneously. Referring back to that 2 in. cube, it is obvious that a 2 in. cube would not set at once, but with an ordinary die casting it will set almost immediately. It is only then that contraction begins to affect any core pins. There is a small amount of strain, but not much. Now, as to whether brass die castings are practical, they

are. I stated, I think, that to make them as pressure die castings, the machines are very expensive to buy and operate, because of the high pressures required (five to seven tons per square inch) and sometimes higher than that. It has got to be hydraulic pressure, and you would not apply that to a small batch. You could not make brass die castings on hand-operated machines.

MR. BROOME: In making the dies you must have distortion eventually, due to heating and cooling. I should imagine that if the metal of the casting shrinks, surely the core does too.

MR. STOCK: This is going to split hairs a little. Actually, the core expands rather than shrinks. You must remember that the core is already very hot, being at a temperature which is made uniform by the number of previous castings passing through it. It maintains this temperature, but the incoming metal is always molten, and as soon as it solidifies it shrinks on to the core, but does not affect it until it begins to harden. There is no particular secret about the metal. It is usually the zinc-base alloys provided by many firms; 95% of the dies we have made are of mild steel. The other 5% are of cast iron or meehanite. In the case of cores, we do occasionally use meehanite because it has a very dense structure and not porous, like cast iron. Then it is used for large cores instead of silver steel. There is no necessity for other than mild steel for the dies. We find it is quite satisfactory.

MR. DELO: Is the expansion of silver steel cores greater than the contraction of the metal, whereby your core will come out more easily when cooling?

MR. STOCK: No. Actually, in theory, a core should be made smaller than you require the hole to be produced, as it has to reach a temperature of 200°F. It varies with the job, and the expansion of that core is going to be very little by heating to 200°F., which is just under boiling temperature.

MR. DELO: Do you keep the cores parallel?

MR. STOCK: We can cast perfectly parallel holes, provided that they are not too long or too great in diameter. There were two holes side by side in the casting you saw. The allowance was five thou, but we could cast within two thou.

MR. BROOME: I notice among the examples a piece with steel insert. Can you tell us how this is arranged?

MR. STOCK: The steel pin is merely inserted into a hole in the die, and the amount projecting is the amount to be included inside the casting, and that amount projecting is knurled or notched.

MR. GALLOWAY: In relation to the drill stand, you stated that the holes were to a tolerance of .0005 in. If a die casting were required to be made appoximately tubular, say, $\frac{3}{4}$ in. outside diameter and $\frac{1}{4}$ in. inside diameter, would you be able to get near that limit on the hole, assuming the casting to be 1 in. long.

MR. STOCK : I think the answer there is that it does depend upon the length of the hole. A shorter hole is more favourable. The longer the hole, the greater the tension with which the casting grips the core. You must have a taper in order to extract the casting. You could not pull them off by any other means.

MR. GALLOWAY : I support Mr. Stock's recommendation of an extension of the present use of die casting. The Institution of Production Engineers is striving to ensure that the limited machine tool capacity of this country is used in the most effective way. The present position would be considerably eased by a wider use of die-casting to eliminate machining operations.

MR. STOCK : Die casting is being taken advantage of very widely but not so much as it might be. Mr. Taylor raised the question of present-day interest in small-batch die casting. It is fairly reasonable to assume that since very large quantity orders are being placed for die-castings, it is only those firms who are prepared to-make sacrifices with a view to post-war orders that are prepared to-consider orders for small batch die casting. The difficulty will arise that only those for a Government contract will be able to obtain release of the material, and interest in small-batch die casting is being deliberately killed for that reason. There is no small-batch die casting on priority work.

I might say that a zinc-base alloy is one that consists almost entirely of zinc. It is generally of the order of 93 to 94% or even higher, and in some cases contains copper, and in all cases aluminium 3 to 4%, so at present-day prices it is quite economical, about £40 per ton (4½d. per lb.). Compared with aluminium it is very favourable. With steel it is not far off the mark, plus the advantage that steel requires machining to shape, and you have to buy a lot more than you want for the job.

MR. BENTLEY : As a visitor to your Leicester branch I must thank you for the opportunity of attending your meeting. I should also like to supplement the vote of thanks for a very interesting lecture. There are one or two points I should like to suggest to Mr. Stock. In the first place, I should like to know (an approximate figure only) the maximum number of small die castings which have been produced per hour. Has the figure of 300 been exceeded ? Also the maximum weight of die casting which has been produced. I should imagine that this is one limitation to the use of die castings. Those we have inspected to-night are limited in weight, and for this reason I should like to know the maximum weight. Reference has been made to zinc base alloys, and also to aluminium bronze. Are there any other alloys which are being used for die-casting ? If I am not asking too many questions, it would be interesting to know the materials which have been replaced by the zinc-base alloys. Generally speaking, when you are producing die-castings

now, are they taking the place of iron castings, or parts made of steel ?

MR. STOCK : Thank you very much for your remarks, Mr. Bentley, and the points you have made, which are very good ones. Production is the worst point, as obviously it depends first on the size of the machine being used to produce the castings, and secondly on the size of the casting, and thirdly on its complexity. If I were to go into the lot I might be here for quite a long time ! If you imagine a small casting (not so small—say 1½ in. square by 1 in. thick) with a hole passing through its centre, and a hole passing through from each of the four sides into the central hole, all having to be die-cast and not drilled, this obviously involves a central core which will be withdrawn or ejected, or the casting will be ejected from it. It also involves four slots, which will occupy room which, if those holes were drilled, would enable you to get more cavaties into the die. Possibly the holes can be drilled more quickly and economically. I think that deals with the last point you mentioned. So far as concerns the number of castings per hour, I will give you the figures of our actual production. We have made a 25-cavity die which has worked, not for five minutes, but consistently at the rate of four shots per minute. This is not bad going. If you have a casting with a heavy core it requires longer, more energy, and is consequently slower. But really I think the question very largely has a relation to the number of cavities you can get into the die. If it is a big casting, perhaps only one, but if small (say ¼ oz.), perhaps a dozen or more—provided it has no complexities.

Regarding the maximum weight, this depends on the size of the machine being used. I think, in fact, this is the only thing it depends on ; and in the case of the machine we have been talking about, it will produce castings 10 oz. in weight. This may not seem very large, but the drill-stand we have seen actually weighs 14 oz. It is 7¼ in. long, 2½ in. wide, and 1¼ in. deep. That was not produced on the machine we have just referred to, but on a slightly larger machine. The capacity is 120 castings per hour, and there are 60 cores to withdraw from it. Die-casting machines which will make castings up to 70 lb. in weight are being made in America, and so far as size is concerned we do know that radiator grilles for motor cars have been die-cast, and only during the last month or two I have heard that ornamental gates have been produced as die-castings. By this I mean those metal gates one sees at the entrance to drives of country houses. These naturally would be more than 70 lb. in weight. I do not know what the maximum will be, possibly of the order of 120 lb.

There are other alloys, but the alloys I have mentioned run into hundreds of types. In the Mazak line there are three distinct varieties of zinc-base alloys, and we used to alloy our own and make

five distinct variations. We now use the standard product. Copper alloys can be varied almost indefinitely. Distinctly separate are the tin-base alloys. There we have covered the range.

Regarding the materials being replaced, I think all the metals you mentioned are covered. Steel, brass and aluminium—aluminium being made as zinc, but more economical. Steel, where it is being replaced by die-castings, is certainly being produced at a great economy in cost, for the reason which I had already mentioned, that you can produce a zinc base for a very small proportion of the cost of steel, while steel has to be machined; but although steel is cheaper, we must buy more than we need, a lot has to be machined away, which also takes time, whereas we get the zinc base casting instantaneously.

Brass was originally used for motor car door handles, wall plates, letter boxes, etc. All these are now being made in zinc-base alloys. Steel parts are not quite so easy to itemize, but cast-iron crank-cases in motor cars are now being produced as die-castings; cylinder heads, pistons (in aluminium) are very good examples of how die-castings have been used in this very beneficial way. Wherever we go we see it. It is not possible to walk through a room without seeing die-castings in every direction. Electric meters, hosiery machinery, advertising novelties and signs, parts of machine tools—it is impossible for me to visualise them all.

PRODUCTION OF DIE TOOLS

Paper presented to the Institution, Sydney Section, by C. K. Fillingham, A.M.I.P.E.

This paper describes the most common machines used in the production of punches and dies. The general principles and applications of the various machines are dealt with, particular attention being given to the Keller automatic copying machines. Examples of punch and die making, using various machines, are described in detail. The discussion deals with materials and production times for die castings, includes further details of punch and die production, and ends with a reference to less conventional dies used for sheet metal pressing.

A LARGE proportion of the articles that we see or use every day of our lives have been either wholly or partly produced with the aid of dies and moulds of one type or another. Our tooth-brush, safety razor, comb, and the car we drive are only possible in their present form and price because of the existence of dies. Panel beating, carving, hand engraving, and embossing are dying trades. In their place we have designers, commercial artists and sculptors who unite their brains and skill to produce models of articles combining utility with beauty. It is a comparatively simple matter with the aid of modern machine tools to copy these models in steel and so produce dies for manufacturing. To-day die tools are on the lips of both engineers and laymen, and so their production is one of great interest and importance to us all and to the Production Engineer in particular. This paper deals with the machine tools and the methods used for the production of die tools.

Machine Tools Used for Die Making.

Machine tool manufacturers have kept pace with and have in many cases anticipated the needs of the die-making trade to a marked degree, making available for our use machines of a wide range of type, size and price. The principal types of machines are metal band saw machines, filing, punching, shaping and milling machines, two and three dimension pantograph profiling and copying machines, hand-controlled duplicating machines, automatic electrically controlled profiling and copying machines, automatic electrically controlled copying lathes, and many useful attachments for milling machines, etc. Size varies from a machine small and sensitive enough to engrave the Lord's Prayer within a .005 in. diameter circle at the tip of a platinum gold wire to one large enough to machine a die weighing perhaps 5 tons, for pressing

the body panel of a motor car. Price may range from less than £100 to thousands of pounds. All of these machines have their own particular sphere of usefulness and careful consideration must be given to the amount and type of work available before selecting the best machine for the purpose.

Metal Band Sawing Machines.

Metal band sawing machines are, in essential details, similar to those so well known in the wood-working trade. The saw is narrow and has sufficient tooth set to enable it to cut a very small radius. When cutting out a die the saw is severed, threaded through a hole drilled in the die block, then brazed together in a few minutes in an electric brazing unit attached to the machine. The saw runs at a surface speed of 30 to 120 ft. per minute, according to the steel being cut. When cutting tool steel of about 50 tons per sq. in. tensile, 1 in. thick, the saw will cut 1 in. length in about three minutes. The work is fed either by hand or weight operated feed, and a line can be closely followed with normal skill and care. These machines are suitable for rough cutting out, blanking and trimming dies or gauges and templates. Initial cost is low, operation is simple, and production times are good.

Filing Machines.

Filing machines are used for finishing dies after they have been cut out on band sawing machines or by any other method. They comprise of a tilting work table and a reciprocating file holder.

Punch Shapers.

Punch shapers, as the name implies, are designed and built for the single purpose of machining punches. The blank punch is secured vertically to a circular table mounted on slides as a slotting machine. The cutting tool (usually a hand-ground tool as used in an ordinary shaping machine) is held in a tool post having an up and down motion. The tool cuts on the down stroke and is caused to tip up at the bottom of its stroke, cutting a radius at the foot of the punch. The tool clears the work on the up stroke. Punches may be quickly machined to such a degree of accuracy and finish that very little, if any, hand work is necessary. The main advantages of the punch shaper for producing punches over other methods are : the simple cutting tools used for the most awkward of shapes, deep grooves and sharp corners can be cleanly cut ; punches can be cut parallel or taper at will ; simplicity of operation, and no special skill is required.

Pantograph copying machines.

These machines are made in two types : two-dimensional for engraving, lettering, and general profiling to uniform depths on

flat or uniformly curved surfaces, and three-dimensional for reproducing small, intricate dies and moulds from enlarged models or patterns. As the name implies, use is made of the well-known principle of the pantograph to give a predetermined ratio of movement between the tracer point and the cutter, which may vary from 1 to 1, to even 100 to 1. The commonest ratio used is 2 to 1.

The work and model or template are mounted side by side, or one behind the other on separate machine tables. The tracer, in the form of a plain pin held in the tracer holder, is moved by hand over the model, causing the cutter, which is either an end mill or a simple half-centre cutter, to move in an exactly similar path, cutting the work in proportion to the model. The tracer point always has a similar outline to the cutter being used. Larger for roughing out, and the same size as the cutter for finishing. Models or templates can be made of wood, metal or artificial stone and are usually two or three times the size of the finished job. Pantograph machines are the best known and most commonly used of all die-making machines, and will probably never be replaced for lettering, engraving, and small mould cutting. They are made by various machine tool makers in a wide range of types and sizes, and many shops doing only a small amount of die making can afford to have one on their floor.

Hand Controlled Duplicators.

Punches, dies, moulds, etc., are produced on these machines from models made the same size and shape as the finished job. The work is mounted beside and on the same table as the mould or template. This table is mounted on ball-bearing slides having a longitudinal and transverse movement, and is hand controlled by a lever having about a 5 to 1 ratio. A vertical cutter spindle over the work and a tracer spindle over the model are connected by a common pinion shaft with a handle at each extremity. Thus, we see that work and model are moved in unison in any direction in a horizontal plane while tracer and cutter are moved together in a vertical plane. Duplicators of this type are not as sensitive as the pantograph machines, but on relatively simple die work and particularly large dies cut from hard steel they are much faster. Their operation is extremely simple, and the control is so light that continuous heavy cutting can be maintained without tiring the operator.

Automatic Electrically Controlled Copying Machines.

These machines are a type unto themselves, so I shall refer to them by their name—Kellers. Kellers are made in a range of sizes, from a small toolroom machine to one large enough to cut a

car body panel punch and die. The principle of operation in each case is the same, so I shall deal in the main with the construction and use of intermediate size designed for the production of dies of all types in an average toolroom. This machine is known as the Keller Automatic Toolroom Machine Type BL.

It is a powerful milling machine operated electrically by push-button control. All movements may be also hand controlled by the use of hand wheels, but these are only intended for setting up. The cutter head spindle is in a vertical plane and is made for the use of taper shank milling cutters. A large range of speeds (from 60 to 3,600 r.p.m.) is provided, so that cutters from less than $\frac{1}{8}$ in. to $2\frac{1}{2}$ in. diameter can be used at efficient speeds. The electric tracer heads are mounted directly above the cutter head and on the same slide which moves vertically in relation to the work. The tracer heads are of two types—profiling and contouring. The former is used for two-dimension work as cutting a punch and die or any uniform depth of cut in the one plane, and the latter for three-dimension cutting of any kind either convex or concave. In each case a tracer automatically follows a model, and the cutter duplicates its path precisely. In the case of profiling, the model may be in the form of a thin metal template. For contouring, a model made of wood, cement, artificial stone or an old die may be used. The work is mounted on a large angle plate within working range of the cutter spindle and the template or model directly above. Space does not permit of a more detailed description of this most interesting and useful machine which is bristling with ingenious mechanical and electrical devices.

This machine is used with great advantage for the automatic production of dies of all kinds, as stamping, blanking, trimming, drop forging, die casting and moulding dies, metal pattern work, and for odd-shaped milling such as cams, etc.

The chief advantages of this machine are as follows: (1) Being automatic in operation, dies are produced independent of any personal skill of the operator, who is free for much of his time to do hand finishing or making preparations for the next job. (2) Worn-out or broken dies may be replaced with the assurance that the new die will be identical with the old, or a broken half of a die may be replaced exactly matching the unbroken piece. (3) Design of an article need not be restricted to suit die-making methods for the Keller can reproduce almost any shape or profile. (4) Absolute accuracy of reproduction and finish are so good that very little hand work is necessary in many cases. (5) Chips cut from the work are readily washed away because the milling cutters work in a horizontal plane. This permits heavier continuous cuts to be taken.

Automatic Electrically Controlled Copying Lathes.

The Keller principle is employed to control automatically the longitudinal and cross feeds of an ordinary lathe in precisely the same path as a tracer point takes as it follows a thin metal template attached to the back of the lathe.

Thus equipped, a lathe can readily and quickly turn bottle moulds, forming rolls, spherical and other shaped punches and dies or any ornamental turning.

Use of Machine Tools for Production of Dies.

Too much stress cannot be laid on the use of modern machine tools for the production of dies. The scarcity of toolmakers and the low standard of those available is well known to us all. So we are forced to be as independent as possible of this variable factor in the production of die tools and seek the aid of the machine to maintain the efficient production and quality of goods which industry to-day demands. A few examples will now be given of die tools produced with the aid of these machines. No attempt will be made to go into full details, only the main points of interest will be briefly discussed.

Making a Small Blanking Punch and Die, Using the Punch Shaper, Metal Band Saw and Filing Machine.

The top face of the punch blank is marked out or a thin metal template is soldered on as a guide for machining. The blank is now secured to the work table of the punch shaper. A suitable shaping tool for roughing out is clamped in the tool post and stroke and speed are set. Slides are operated by hand and the punch is roughed out to within about .005 in. of template or marking. A finishing tool is now used to shape punch to size, the stroke of machine being shortened so that the tool will not be cutting on the roughed-out foot of punch. Some machines have a small microscope attached to enable the operator to split easily a line. The punch is now held firmly on the die blank and the outline marked with a scriber, or, better still, type metal is cast round the punch, machined flat to the form of a thin template and attached to the die blank. A hole is now drilled in the blank, which is then taken to the band saw machine. The work table is tipped from 2° to 5° for clearance, the cut band saw is threaded through the hole in the blank and the table, and the ends brazed together. The speed is set to suit the material being cut, and the operator cuts out the blank, running as close as possible to the line marking or template. Hand pressure or weight-operated feed may be employed ; this is a simple process not requiring much skill. The die is now taken to the filing machine. The machine table is tipped to a little less angle than was used on

the sawing machine, so that the file is not cutting on full depth of the die. A suitable file is chosen, passed through the die and clamped in the file holder. Filing now begins, operator hand controlling the die and working to marking or template. If template is used it is a simple matter to notice when file touches template. Various files are used and the punch is tried in the die from time to time until suitable clearance is obtained. The punch is usually made long enough so that a portion may be cut off and used as a blank ejector in the die set.

Using a Keller for Producing a Blanking Punch and Die.

A thin metal template is made to the same size and outline as the blank to be produced or a sample blank may be used. This is attached to the template holder on the upper part of the angle plate and the punch blank is secured to the lower part. They need only be approximately the same distance apart as the cutter and tracer head, because the tracer head can be moved relative to the cutter head over an area of about 10 in. by 5 in. For this class of work the profiling tracer-head is used. Setting points are mounted in cutter and tracer heads, and the tracer head moved until setting points coincide with centre lines on the work or template. A suitable milling cutter is chosen, perhaps 2 in. by $\frac{1}{4}$ in. diameter, and a plain tracer point about $^1/_{32}$ in. bigger in diameter than the cutter. Suitable cutter speeds and feeds are selected and the depth of cut set, which could be up to $1\frac{3}{4}$ in., using the cutter mentioned. Appropriate control buttons are pressed, starting cutter spindle motor, feed motors, suds pump motor, etc. The directional control ring at back end of profiling tracer head is turned to guide the tracer towards the template. The cutter ploughs its way through the punch blank and will continue in a straight line until the tracer meets the template, when it will change its course and follow exactly the outline of the template no matter how odd the shape. The operator's only job is to turn control ring so that pointer is approximately 45° to the part of template being followed. This requires no skill at all. After going right round template a small tracer is used, only about .004 in. larger in diameter than the cutter, and the operation repeated. The punch outline will now be precisely the same as the template. A much smaller cutter may be used if the job has sharp corners or deep grooves in it. If taper clearance is desired a tapered cutter is used.

Type metal is now cast round the punch, and the outline thus produced is mounted on the machine in place of the template. The die blank is mounted and cut in the same manner as the punch. Any desired clearance between punch and die can easily be obtained by using a tracer point smaller than the cutter. Stripper or blank ejector can be cut out in the same way. These templates are now

stored safely away for replacing broken or worn-out punches or dies which will be identical with the original. The advantages of this method are self-evident.

Producing a Small Moulding Die on a Three-Dimension Pantograph Machine.

The following description could apply to any cavity mould for making an article such as a comb, electrical fitting or novelty. A wood model is hand made twice full size, care being taken that there is a small amount of draft on all sides. This model is mounted on a plate and a frame placed round it. Moulding material used like plaster-of-paris but much harder is poured over the model and allowed to set. This negative working model is mounted on the machine under the tracer point. The die blank is clamped on the work table under the cutter spindle. The ratio of the machine is set at 2 to 1, suitable roughing-out cutter and tracer point to match are selected, and cutting begins. The operator hand guides the tracer in the cavity of the model, while the cutter is reproducing the shape in the die. Cutters and tracers are changed from time to time, various shapes and sizes being used until the smallest and deepest part of the cavity has been cut. Any lettering, trade marks, etc., that have to be cut in the dies are produced from master letters or templates. Any marks or blemishes in the model, being only half the size in the die, is one advantage of this method. Another is that the operator can put a lot of pressure on the cutter, while roughing out a simple part of the die, but can instantly slow down and pay more attention to an intricate part.

Cutters are usually of the half-centre type and run at high speeds up to 10,000 r.p.m.

Finish and accuracy of reproduction are of such a high standard that very little, if any, hand finishing is required.

Machining a Die for a Radio Cabinet on a Keller Automatic Toolroom Machine.

A wooden pattern is made full size plus shrinkage of moulding material to be used for cabinet. The pattern can be cut down or added to until a satisfactory shape is achieved. It may then be painted the colour of the finished article, control knobs, etc., attached and passed round to all concerned for comment. After final shape and design have been reached, knobs, etc., are removed, holes and blemishes waxed up and pattern is smoothed and lacquered. It is then attached to a flat plate, a frame is clamped in position, and moulding material is poured over the pattern. So we get our negative working model which is attached to the angle plate of a Keller within range of the tracer spindle. The blank die block which might weigh about half a ton is then clamped

in position on the lower half of the angle plate. The tracer head is moved until tracer head and cutter head are in correct relationship to the model and the die block. Use will be made of both the profiling and contouring tracer heads, the automatic contouring tracer head being used for roughing out. Various stops, controls, speeds and feeds are then set. I might point out here that one of the most important things to do before any job is put on a Keller is the selecting and making if necessary of the various cutters and tracers that will be required. Much time will be saved if careful consideration is given to this point. A large ball nose end mill about $1\frac{1}{2}$ in. diameter and a tracer about $\frac{1}{8}$ in. larger in diameter will be used for roughing out. The cavity being too deep for the cutter to go right to the bottom in one cut, a depth stop is set allowing the cutter to penetrate to a depth of about $1\frac{1}{2}$ in. from the face of the die. Various control buttons are pressed, and cutting begins. Vertical or horizontal cutting can be employed at will, but in this case vertical is preferable because chips fall from the work more readily. The tracer moves up in mid-air $1\frac{1}{2}$ in. from the face of model until it comes in contact with the outline of the cavity, when it will start to back out and follow the line of the model until right out. The feed then reverses and the tracer moves down and into the cavity again. At the same time the model is fed sideways a predetermined amount. So the tracer goes down until it meets the bottom of the model. It will then back out, reverse and feed sideways, and so on. This motion continues automatically, without any assistance from the operator, until the end of the cavity is reached. The operator then sets the depth stop to take a deeper cut and reverses the control so that sideways feed takes the tracer in the opposite direction. This continues until the bottom of the cavity is reached. The depth stop is then set clear, allowing the tracer to follow precisely the contour of the cavity. Cutters and tracers used from then on will be of such a size, shape and length that the deepest part of the cavity and the smallest radius will be reached. The profiling tracer head will then be used, and instead of the tracer travelling up and down and feeding sideways it will go around the inside of the cavity and is fed in manually at the end of each round. This method will produce a better outline than contouring. Then back to the bottom, which will be finished partly by contouring and partly by profiling with a variety of cutters and tracers. This is not a fast process. Some corners might have to be nibbled at with a slender cutter for hours, but the important point to remember is that almost any shape can be faithfully reproduced from the model. The force for the inside of the cabinet can be produced in like manner only the tracer is going over a raised model instead of in a cavity. Much hand work is, of course, necessary on a die of this description before it

is ready for moulding a cabinet of high quality and finish. It is common practice to case-harden, polish and chromium plate the cavity of a die to give it a long and useful life.

This description in general might apply to the production of almost any cavity die for bakelite moulding, die casting, drop forging, etc.

Discussion

VISITOR: Does the combination tracer head combine contouring with the other movement?

MR. FILLINGHAM: Yes. I have here the combination tracer head which actually combines the two movements, i.e., profiling and contouring. If the tracer point comes into contact with the template in front of the model it will continue to follow round the outline of the template. That is simple profiling. But it will also go in and out, over any impression of the model while going around the template, thus combining profiling with contouring. It is difficult to explain exactly how it operates—it would be far easier to see the machine working to show you what actually happens.

MR. DAWSON: With regard to die-casting, have you got down to a metal yet which is better than lead? I have had some trouble when it comes to the matter of repairing die castings. It has been really frightful; you could not solder it.

MR. FILLINGHAM: Most of the samples here are brass die castings, which can be readily machined or soldered, but some are made of zinc base casting metal, which flows more readily. They are sounder than sand casting.

MR. DAWSON: Regarding metal for die castings, have you been able to supply castings in gun metal, or good sound brass, similar to sand castings regarding machining capabilities? Mostly die castings, in the past, have been made from very poor material. Is this because you must have a metal with a low melting point in order to prolong the life of the die?

MR. FILLINGHAM: The steel most commonly used is 10% tungsten hot die steel, it is frequently red hot all the time while in use. Many of those dies have produced 100,000 castings before the dies have failed. When a die cracks and fissures open up, a new one has to be made. The particular casting I have in my hand was made from a new die after only a few hundred shots.

MR. OLIVER: Would you suggest it was the fault of the steel, even though the best is used?

MR. FILLINGHAM: Yes; no hot die steel will stand up indefinitely without failing. When brass is forced into the die, red hot, the die develops surface heat cracks because of the expansion of the surface without corresponding expansion of the whole die. Nevertheless, steel has improved during the last few years. When hardened at 1175°C. and tempered at 700°C. it has some of the qualities of high speed steel.

MR. JOHNSON: As the octagonal cover die was machined out of

the solid by means of circular milling cutters these would naturally produce their own contour at the corners of the octagon. Would Mr. Fillingham please explain the method used to bring the corners of the die to the proper angle.

MR. FILLINGHAM: Yes. We made a hob which was forced into the steel die after the impression was cut at about 500 tons pressure. The hob was made on a Keller, and the various impressions cut by profiling.

MR. DAWSON: Would it be possible to have sharp corners on any shape?

MR. FILLINGHAM: Yes. On this job you see the corners have been improved by hand. The range of speed of the machine is very great, varying from 80 revs. to 3,600 revs., so a very small cutter can be used at efficient surface speed. We use a very small cutter for the final finishing whether it be hexagon or octagon.

MR. DAWSON: The sharp corners are obtained by hand?

MR. FILLINGHAM: Yes.

MR. OLIVER: Can you give some indication of the maximum amount of metal removed per hour from a fairly heavy die block?

MR. FILLINGHAM: I can give you a good idea. You remember the die I showed you which produced that telephone hand set base. The first cutter used was $1\frac{1}{8}$ in in diameter, cutting $1\frac{1}{2}$ in. deep, and the feed 2 in. per minute longitudinally; the sideways feed being $\frac{3}{4}$ in., so each cut removed a slab of metal $1\frac{1}{2}$ in. deep by $\frac{3}{4}$ in. wide at the rate of 2 in. per minute. For profiling, the range of feed is from .8 in. per minute to as high as 6 in. per minute. With the aid of interrupted feed mechanism, the feed can be cut down so as to hardly move. Even with a device for cutting down the feed, a small cutter will easily break. We did have some figures available showing how much metal can be removed from a big machine, but I do not remember them.

MR. C. G. CRANE (*Chairman*): Roughly about 1 lb. a minute, I think.

MR. MARNER: I have had trouble roll-threading small die castings in brass. Can you tell me of some reason for this?

MR. FILLINGHAM: When a die casting has to be roll-threaded the alloy is different from ordinary die-cast metal. Mr. Crane may be able to give some reason for it.

MR. CRANE: I have not heard an explanation except that when the metal is forced into the die you get a slight surface crystallization, which may affect the thread rolling.

MR. FILLINGHAM: Die casting brass runs far more easily than sand cast. Tools have a very long life machining die cast brass.

MR. OLFEN: How many shots per hour would you get from a casting of that type?

MR. FILLINGHAM: Approximately 500 a day.

MR. OLFEN : About 50 an hour ?

MR. FILLINGHAM : Yes, more than that perhaps.

MR. OLFEN : In that particular die you only got one in each shot ?

MR. FILLINGHAM : Here is a better example where we get two. In some dies you can get as high as 10,000 parts a day from one die, and that can be kept up constantly.

MR. MARNER : Have you had any experience with hard chromium steel ?

MR. FILLINGHAM : I have heard of various new steels being recommended during the last few years ; but we still use 10% tungsten steel. It can be readily machined and does not warp appreciably. The life of a die is very great and you can get 100,000 shots from one die.

MR. MARNER : I have heard that they use chromium-plated steel dies for drawing shell cases ?

MR. FILLINGHAM : We know that chromium plate is used extensively, but I do not know how chromium plated steel would act on a hot die.

MR. MARNER : It is used frequently up to temperature of 600°C. for many hours at a stretch.

MR. FILLINGHAM : It may be possible. It is interesting to hear that.

A VISITOR : Can you tell me the time it took to produce that radio cabinet ?

MR. FILLINGHAM : Yes ; it took about 150 hours work or more. The telephone base would take about 120 hours' work, and a very fast feed was used in that particular case.

A VISITOR : On the question of saving time, is there any other way of making that particular die ?

MR. FILLINGHAM : There are other methods which might produce that die more quickly, but the Keller has many advantages ; it does many things which other machines cannot. One advantage of the Keller is that you can make any shape of article with one handling. You can make many dies in a very short time. That car handle die was very quickly made. By other methods it would take far longer, even on a pantograph machine. You can hardly imagine any method which would be an improvement on the Keller. Both male and female punch and die were produced from a simple model and I believe there was no hand finishing beyond just a little surface filing. A small cutter was used to provide the ridges. It was a simple matter to put in a small tracer and cutter and the cutting of the grooves can be controlled by the tracer point. It would be most difficult to produce it by any other method.

MR. DICK : Was that die made of mechanite ?

MR. FILLINGHAM : Yes. It was heat treated before we machined it. The tensile strength was about 60 tons and it was very hard to

machine at first. Subsequently another die was made of slightly softer metal.

MR. PARKINSON: I must thank Mr. Fillingham for his excellent paper. It is obvious that he gave a considerable amount of time to its preparation, and he has given us an excellent description of the Keller machine with which quite a number of us are familiar. It is an excellent machine, and no doubt after working this type of machine for some considerable time Mr. Fillingham has become "Keller"-minded.

Machines of this kind go a good distance towards completing many types of dies, but I am waiting for someone to come along with a machine with a different application; that is a machine to polish moulds for plastics.

We have heard to-night a good deal about making moulds and dies of all types by modern methods, and as a matter of interest I will tell you of another type of die making I saw successfully applied only a very short time ago.

The first was dealing with sheet metal blanks about 2 ft. in length with various projections on the outside edges. These projections or lugs had to be bent at right angles to the main body of the blank. The bending operation was carried out in a hydraulic press, and the male part of the die was mounted to a fixed table. Position pins were placed on these to locate the blank, but no female die was made. All that was used was a very large piece of sponge rubber attached to the moving ram of the press. The finished job was quite satisfactory.

Another job which interested me was the bending of thin sheet metal parts to some rather awkward formed shapes. The male and female dies were cast in lead alloy in wooden frames. Attached to a drop hammer the blanks were suitably located on the bottom tool and by the judicious application of pieces of sponge rubber acting as pressure pads, some really excellent work was being produced. I mentioned this solely to indicate that there are many short cuts which can be taken in the production of dies.

I have enjoyed this paper and the discussion, and have very much pleasure in proposing this vote of thanks.

The vote of thanks was carried by acclamation.

THE VALUE OF SUBSTITUTE PROCESSES

By D. F. Galloway, Wh. Sc., B.Sc., A.M.I.Mech.E.

This article suggests substitution of processes as a means of releasing machining capacity and thus relieving the acute shortage of machine tools, small tools and relevant toolroom capacity. The principles of substitution, including modification of design and reconstruction of production layout to reduce or eliminate machining processes, are illustrated by a number of examples. These examples of the use of pressing, die-casting, welding, etc., as substitute processes form part of an unlimited range of possibilities with which resourceful and experienced production engineers can meet the present emergency.

TO-DAY industry is faced simultaneously with the immense problems of restricted supplies and greatly increased demands. Highly mechanised armed forces impose such a heavy burden upon our production plants, that it becomes imperative to make the utmost use of every available worker, every available machine, and every available scrap of material. To achieve this extreme degree of economy it is often necessary under present war conditions to adopt a procedure which in time of peace may be undesirable. Such departures from standard practice have already taken place in the reorganisation of labour and in the use of substitute materials. Nevertheless, there still remains tremendous scope for substitution of *processes* in order to overcome the acute difficulties caused by our restricted machine capacity.

The necessity for such substitution was recently stressed by the War Emergency Committee of the Institution of Production Engineers in their memorandum to the Production Council of the Cabinet. In this memorandum the importance of replacing, where possible, machining operations by pressing operations, was pointed out as a means of conserving our restricted machining capacity, and of utilising the comparatively plentiful pressing capacity.

The effective substitution of processes is dependant upon the production engineer who must have sufficient experience and vision to recognise suitable components and to re-arrange their layouts. The re-arrangement of layouts offers unlimited scope for engineers with a thorough knowledge of organisation and a keen appreciation of the possibilities and limitations of the individual processes of fabrication. Such intimate knowledge of all the various methods of manufacture is essential to achieve effective substitution for it is impracticable to formulate rigid rules, and the general principles of substitution must be applied to each individual component in the light of previous production experience.

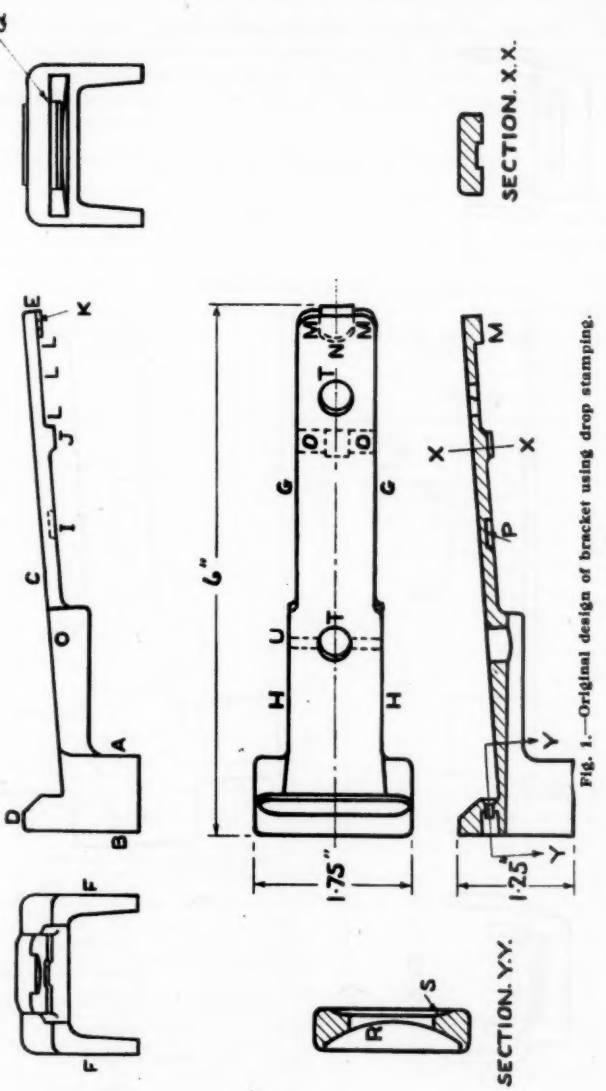

Fig. 1.—Original design of bracket using drop stamping.

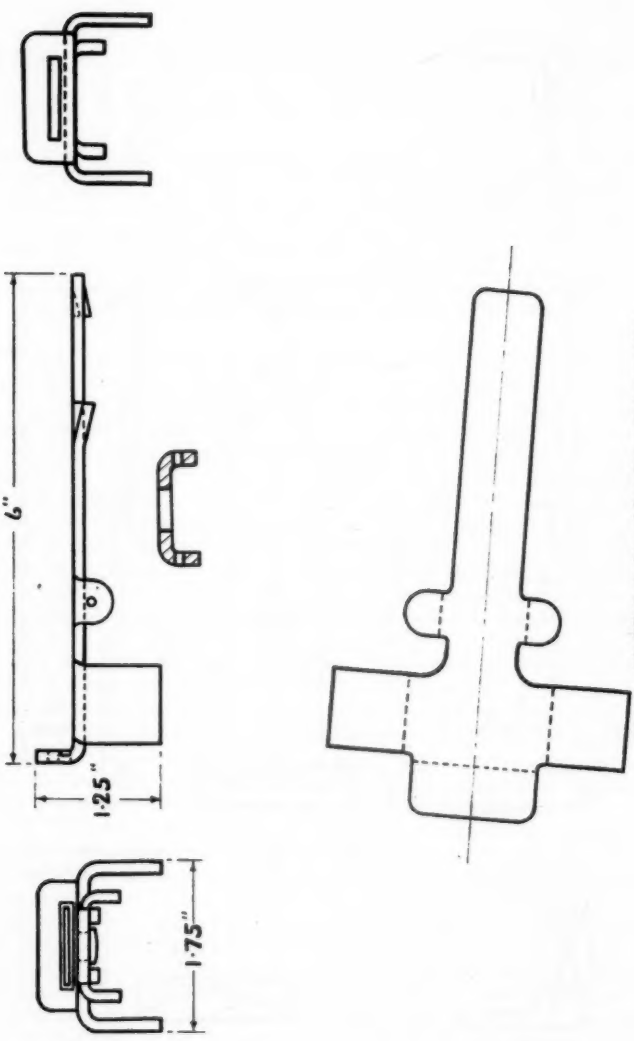

Fig. 2.—Modified design of bracket using pressing.

In the following pages a few examples of substitute processes are given, including replacement of machining by pressing operations, and by die casting, substitution of welded components for machined castings and forgings, and the use of shaving to eliminate grinding and other processes.

Substitution of Pressing for Machining Capacity.

As an example of the type of substitution referred to in the Institution of Production Engineers' memorandum two alternative methods of manufacturing the bracket shown in Figs. 1 and 2 are

TABLE No. 1.—COMPARISON OF LAYOUTS FOR BRACKET

Original Design using Drop Stamping		Modified Design using Pressing	
Opn.	*Description*	*Opn.*	*Description*
1	Stamp	1	Blank.
2	Heat treat	2	Form.
3	Mill face A	3	Shear and bend stops.
4	Mill face B	4	Spline mill slot.
5	Mill face C	5	Broach ends of slots.
6	Mill faces D and E	6	Drill.
7	Mill sides F	7	Coin chamfer of slot.
8	Mill sides G and H	8	Burr.
9	Mill face I	9	Stamp No.
10	Mill faces J and K	10	Brown.
11	Mill slot L		
12	Mill lug M		
13	Mill radius N		
14	Mill slot O		
15	Mill slot P		
16	Drill holes in corners of slot Q		
17	Mill radius R		
18	Mill slot Q		
19	Mill radius S		
20	Broach slot Q		
21	Drill two holes T and one hole U		
22	Lightly fraze all holes		
23	Trim, stamp numbers, etc. ...		
24	Brown finish.		

given. In the original layout the bracket was made from a drop stamping which was heat treated and machined. The scheme of manufacture indicated in the left-hand half of table No. 1 comprised 24 processes including 16 milling operations and two drilling operations. On mass production this involved 50 milling machines and two drilling machines and necessitated the use of at least 50 jigs and fixtures. By modifying the design and layout as shown in Fig. 2 and in the right hand half of Table I, the total number of processes was reduced to 10 including one milling operation and one drilling operation.

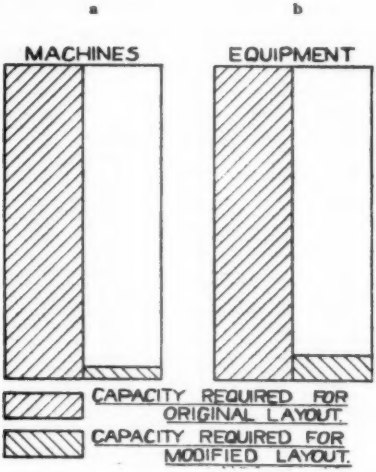

Fig. 3.—Machine and equipment capacity required for original and modified brackets.

The prime object of this change was to release machining capacity and to utilise pressing capacity, and the extent to which this object was achieved can be judged from the layouts and from the diagram 3 (a) which represents the milling and drilling machine capacities required. Numerous other advantages inevitably accrue from this drastically modified method of manufacture. The importance of reduced production time and smaller capital tie-up is obvious and a comparison of the equipment required, Fig. 3 (b), shows how effectively the modification transfers pressure from those sections of the toolroom already overburdened by exceedingly heavy demands for small tools to the comparatively free sections engaged on die-work.

Substitution of Welding for Machine Capacity.

Despite the amazing growth in the applications of welding during recent years its fullest use is still impeded by ignorance and lack of confidence. Abundant evidence is available regarding the scope of various forms of welding, and the strength and degree of accuracy to be expected in the case of components built up by any particular method.

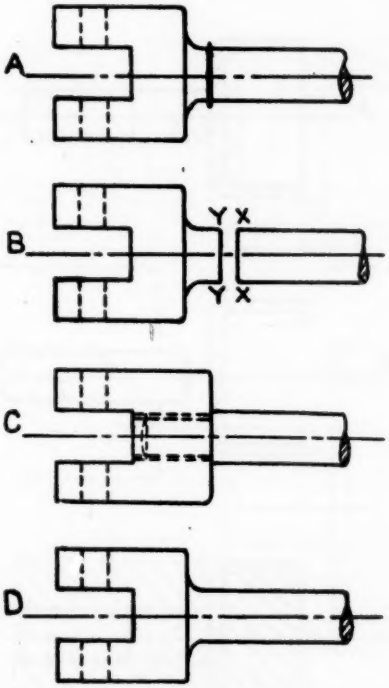

Fig. 4.—Heavy fork-ended connecting bar. A—flash welded. B—parts before welding. C—screwed head. D—forged head.

Under present circumstances welding can be used to release considerable quantities of machining capacity and often to replace difficult forging operations.

The heavy fork-ended connecting bar shown in Fig. 4 (a) is an example of how *flash welding* can be used to eliminate an awkward

forging, Fig. 4 (d), or an unsatisfactory screwed joint involving additional machining, Fig. 4 (c). In this form of welding the ends XX and YY, Fig. 4 (b), which may be several square inches in area, are merely welded together by the passage of a heavy current while the fork-end and the rod are held securely by clamping electrodes. The resultant joint is as strong as the parent metal and the rod length can, if required, be controlled to within $\pm$ .010 in. When the weld is complete it is usual to grind off the small fin created at the joint.

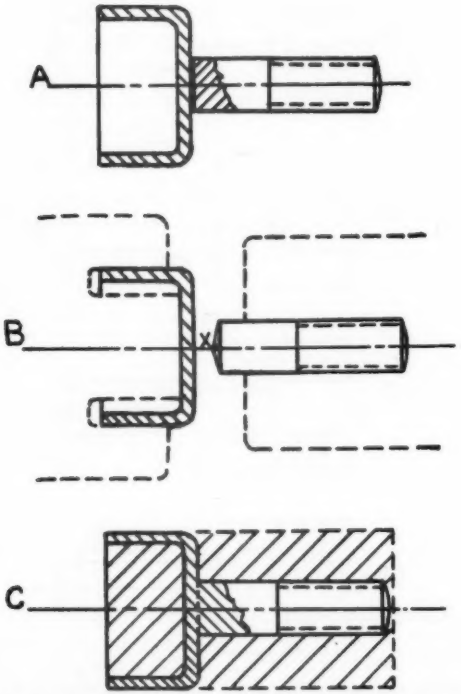

Fig. 5.—Cup-headed stud. A—projection welded. B—parts before welding. C—excessive stock removal if made from solid.

The cup-headed stud, Fig. 5 (a), is an example of how *projection welding* can be used to release considerable turning capacity by combining a small pressed cup and a simple plain stud. The stud end X is formed so that it projects towards the cup. The two parts

are held in special electrodes as indicated by dotted lines, Fig. 5 (b). and fusion takes place when the projection X is brought into contact with the cup base. This process is very similar to spot welding only the current is localised by the shape of one of the mating surfaces instead of by the shape of the electrodes. Unlike the flash welded joint, the projection weld rarely attains the strength of the parent metal but for small areas of weld the result is satisfactory. If the

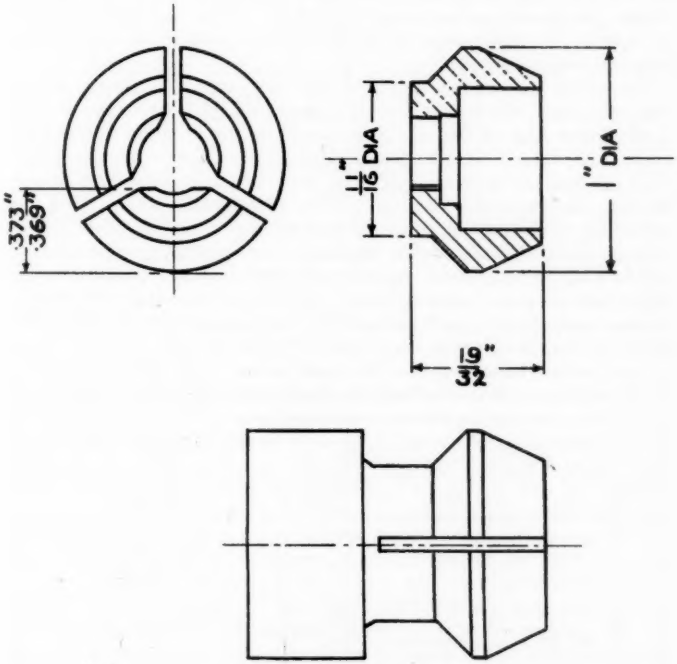

Fig. 6.—Loose collet jaws.

component were produced by machining from the bar a considerable quantity of material shown shaded in Fig. 5 (c) would have to be removed from both ends of the workpiece.

It is clear that in addition to the release of machining capacity considerable savings in man-hours and overall costs are effected by the modification of production methods and the use of welding as a substitute process.

Substitution of Die Casting for Machining Capacity.

Die casting is another process which can often be used to release considerable quantities of machining capacity. In order to make full use of this form of substitution it is generally necessary to change the material from which the component was made. In cases where the physical characteristics of the die cast metal are inferior to those of the material originally used, it is often possible to modify the design of the component so that it functions just as efficiently. Where the durability is reduced the effect is often completely counteracted by the cheapness of the substitute product which permits frequent replacements.

The collet jaws shown in Fig. 6 were originally made from bright mild steel bar, which was turned and parted off in the form shown in the lower half of Fig. 6. This was then slit in three places 120° apart, and then re-chucked and parted off to form three separate jaws. A tedious burring operation was then necessary and finally the components were cadmium plated. Production was carried out according to the layout shown in the left hand side of table No. 2, and involved the use of one capstan, one second-operation lathe, and two milling machines together with the necessary turning tools, drills, cutters, and special fixtures. By using a zinc base die-casting *all* this machining capacity is released as indicated by the modified layout shown in the right-hand side of table No. 2.

TABLE No. 2.—COMPARISON OF LAYOUTS FOR COLLET JAW

Original Scheme using Bright Bar.		Modified Scheme using Die Casting.	
Opn.	*Description.*	*Opn.*	*Description.*
1	Face end, turn, form angles, drill, bore, and part off.	1	Cast as separate jaw (three jaws, i.e. one set per cast).
2	Saw cut slots.	2	"Parkerise" and oil.
3	Part off to $\frac{11}{16}$ in.		
4	Mill flat to $\frac{5}{8}$ in. dimension ...		
5	Remove burrs		
6	Cadmium plate		

Although the use of die-casting has greatly increased, the potentialities of the process are far from being fully exploited. Often the amazing speed of production and the dimensional accuracy which can be achieved by this process are not fully appreciated. Moreover, the fact that it is rarely necessary to machine the castings not only releases machining capacity but also conserves material, since no scrap is produced in the form of swarf.

Shaving as a Substitute Process.

The ball pin, Fig. 7, is an example of the type of component upon which shaving can be effectively used as a substitute process. This component is similar to the ball pin used in the steering mechanisms of many automobiles, and the function of the ball is such that it must fit accurately in the socket of the joint and must have a well finished surface to permit sliding without excessive friction and

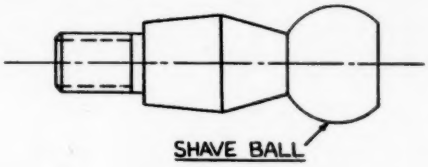

Fig. 7

wear. If a shaving operation is performed upon the ball after forming, the precision and fine finish achieved are such that it is only necessary to polish after hardening. Thus the inclusion of this simple shaving operation releases the machine capacity and eliminates the labour which the alternative form grinding operation would involve.

The foregoing illustrations of substitute processes indicate but a mere fraction of the unlimited range of possibilities which lie in the hands of production engineers. Unfortunately, some engineers regard the incidence of war as a signal that changes of designs and alterations of layout must cease because they impede production. Such stagnation is most undesirable, for even if the methods of production were ideal under pre-war conditions, the violent changes affecting demand, materials, labour, equipment, etc., necessitate a thorough examination of general layouts and of individual operations. All details of production must be scrutinised if maximum output is to be achieved. Whether improvements take the form of small modifications of feeds and speeds, or involve substitution of processes, or are even so drastic as to involve the complete elimination of a process, inertia and convention must be overcome and the necessary changes made.

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HIGHER NATIONAL CERTIFICATES IN PRODUCTION ENGINEERING

The first meeting of the Joint Committee for Higher National Certificates in Production Engineering was held on March 18, 1941, when arrangements were made for bringing the scheme into operation.

The Joint Committee is representative of the Institution of Mechanical Engineers, the Institution of Production Engineers and the Board of Education.

The Education Authorities and the Technical Colleges and Schools are being notified of the Rules and other particulars drawn up by the Board of Education and approved by the Joint Committee.

In addition to the Higher Certificates, Ordinary National Certificates in Mechanical Engineering with approved production engineering content will be countersigned on behalf of the Institution of Production Engineers by its President.

Schemes submitted by September, 1941, which are adopted by the Joint Committee, will come into effect so that the first examinations under them can be held the following year.